Distributed Production of Fuels & Chemicals from Stranded Natural Gas

EXECUTIVE SUMMARY

In the Sixty-First Legislature of the State of Wyoming 2012 Budget Session House Bill No. 0121, Enrolled Act No. 25, House of Representatives was passed by the full Legislature and signed into law by Governor Mead. This legislation authorized studies to identify:

- Whether a commercial scale facility which converts minerals to value added products would be economically viable in Wyoming given projected energy prices and regulatory trends;
- Attributes unique to the state of Wyoming which mitigate for and against construction of a commercial scale minerals to value added products facility in the state;
- The best available technologies for the commercial scale conversion of minerals to value added products in Wyoming;
- Potential obstacles to the construction of a minerals to value added products facility in Wyoming and possible strategies to address those obstacles, including, but not limited to the following:
    - Regional and national political climate;
    - Economic issues;
    - Regulatory issues; and
    - Transportation.
- Potential input sources of minerals and water for the facility and potential markets for the final value added product and any other products created during the conversion process; and
- Whether, and at what level and in what form, state support is necessary for the development of such a project. The study shall identify possible state incentives available for the construction of commercial scale minerals to value added products facility and determine which incentives are likely to have the most benefit to industry and the citizens of the state of Wyoming.

Western Research Institute (WRI) proposed a techno-economic assessment of Wyoming's stranded natural gas resource emphasizing technologies to convert gas into liquid transportation fuels and chemicals such as gasoline, diesel and olefins. The results of the assessment are presented in this report.

In previous studies, economy-of-scale considerations have dictated that gas-to-liquid (GTL) facilities must become quite large with capital investments approaching several billion dollars. However, recent technological developments in catalysts and smaller, more efficient modular reactors make thermo-chemical conversion of natural gas into fungible fuels and chemicals an attractive option for monetizing Wyoming's stranded natural gas resources even at a smaller scale. Advancements in control systems make remote management of distributed modular plants possible from a central facility. Similarly, a central facility can service modular synthesis reactors and gas clean-up modules. These and other similar concepts and strategies make distributed GTL

conversion possible in remote locations such as conversion at the point of production into an easily transportable, value added, and marketable commodity.

A team of WRI scientists and engineers was assembled to conceptualize a reference GTL plant to produce gasoline from natural gas, and to identify potential candidate sites. Process simulations were conducted to establish key inputs such as water requirements, and to quantify solids and gaseous emissions and effluents. Vendors were solicited for budgetary price quotes, allowing capital cost to be estimated. The operational needs of the plant and costs for those needs were estimated based on information from industry contacts, so that annual production cost could be estimated. Finally, the body of published information including the Energy Information Administration's reports was consulted for views on the economic outlook of the proposed facility. In order to address the issues of interest to the Wyoming legislature, WRI engaged Associated Legal Group, LLC to address legal issues pertaining to the distributed deployment of the GTL technology. A refinery expert was also engaged to assist with product evaluation and product market assessment for completing a process economic evaluation.

The proposed plant configuration is a compact, modular process that can be assembled at a fabrication shop and delivered to a natural gas field requiring minimal field assembly. Conversion is carried out without expensive oxygen and with minimal water consumption. Advanced controls allow remote operations and process control of a single or distributed set of units by a remotely monitored, semi-automatic control station to produce and store the product. Modular design will also allow field replacement of components such as desulfurization modules and reactor modules. Refurbishing of gas clean-up modules and catalyst reloading/regeneration is similarly affected in central facilities. Small modular units reduce manufacturing costs and provide scalability.

For this study, the term Wyoming Stranded Gas Process (WYSG) refers to gas-to-liquid technology that converts natural gas into a gasoline product. By selecting gasoline as a GTL product we do not intend to overlook that similar concepts apply to conversion of natural gas into a diesel product, mixed alcohols or other chemicals. In the most part, the modularization concepts and related scale-up considerations, permitting requirements and other items are equally valid for nearly all the value added products possible displayed in Figure 1. A reference plant size of 150 bbl/d capacity was arbitrarily selected representing a size suited for a small production facility.

WYSG process involves three basic steps:

- Reforming of natural gas to syngas
- Conversion of the syngas into methanol (STM)
- Methanol transformation to gasoline (MTG)

All of these conversion steps are catalyzed reactions that have been commercially available in different forms for decades.

Stranded gas is described as natural gas reserves that are impeded from getting to market by either

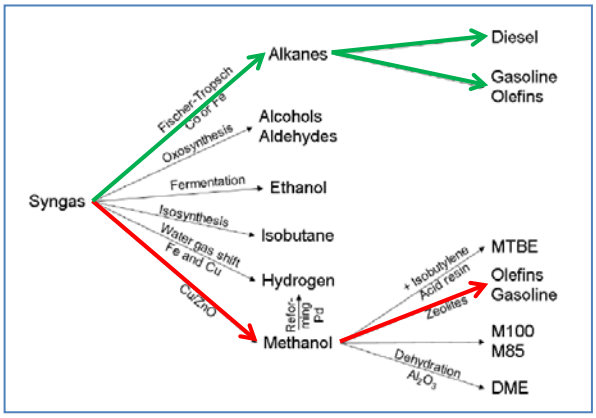

Figure 1 Conversion Pathways

physical or economic hurdles. These hurdles can vary from one well to the next. With the local price of natural gas at around $2.00/Mscf, all of Wyoming's natural gas could be considered economically stranded.

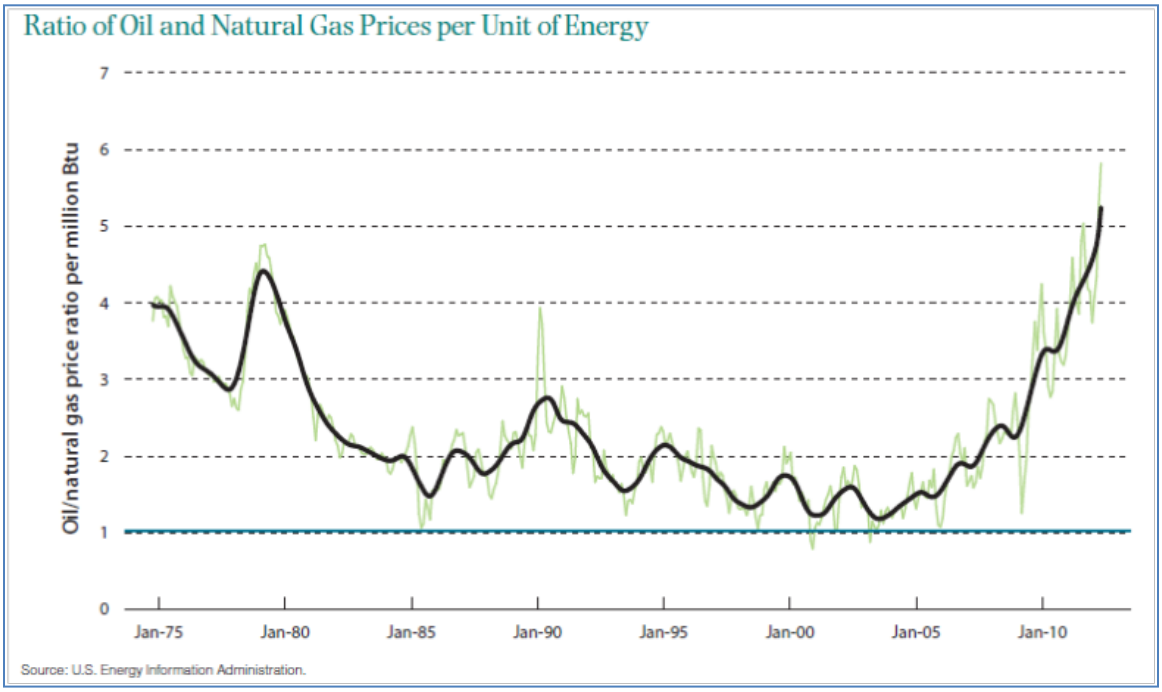

Figure 2 Historical Price Ratios for Oil and Natural Gas

For the last thirty years the price of natural gas and the price of crude oil have been linked. As shown in Figure 2, over the last two years the linkage between the two prices appears to have been broken. A very large percentage of crude oil is used to make fuel for the transportation sector, and the transportation sector makes no significant use of natural gas for fuel. The nationwide natural gas production in 2011 was nearly 12 percent above the 2009 level, and a record production is expected in 2012 and beyond. These large increases in supply are the main reason that natural gas prices have fallen to such lows. As the consumer market takes note of the large price differential between natural gas and fuels derived from crude oil, demand for natural gas will likely increase. However, factors such as increased shale gas, associated natural gas, and coal bed natural gas production will likely keep the prices low into the foreseeable future. Lower gas prices represent a major incentive for WYSG-like GTL conversion into transportation fuels.

A simple block flow diagram of the nominal 150 bpd gasoline WYSG process is depicted in Figure 3. The final product can be sent to refineries. Following sulfur removal, the three conversion steps are catalyzed reactions that have been commercially available in different forms for decades. For each of these three steps there are various choices available in regard to equipment and catalysts, and some technologies are better suited than others to the conditions that will be prevalent at remote natural gas wells. As a part of the study, many decisions were made to exclude various pieces of equipment that are typically included in the design of larger plants. These decisions were made for the sake of minimizing capital cost and facility footprint, two constraints that have the potential to

limit the practical application of this type of plant. Two notable exclusions included eliminating the use of oxygen for reforming and forgoing recycle of unconverted syngas. Unconverted syngas is instead used as a fuel to process a steam-methane reformer.

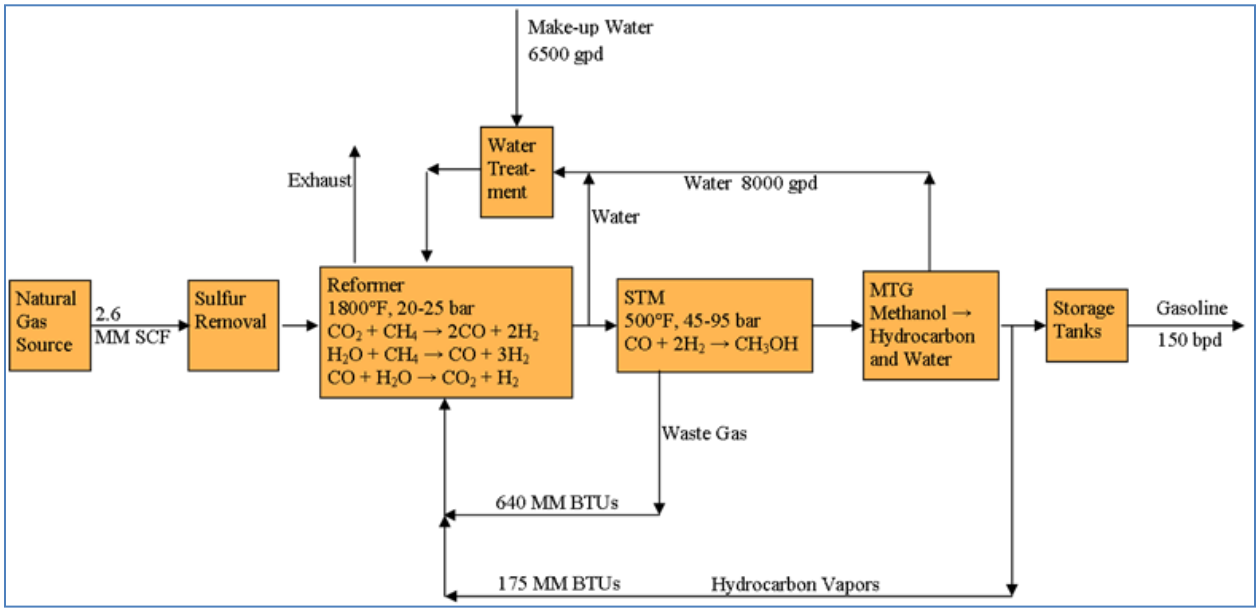

Figure 3 A schematic of proposed WYSG process

Water and natural gas are the main inputs to this process. The water is used to make steam, which is combined with the natural gas in the reforming step to produce syngas (CO and H_2). Pure oxygen or carbon dioxide could be used in place of steam as a source of oxygen for the reforming step, but the associated costs are prohibitively large for this size of plant. Another advantage of steam-methane reforming is that any CO_2 present in the feed natural gas improves process efficiency. Steam-methane reforming results in a syngas composition with a H_2/CO ratio around 4 to 1. The ideal ratio for subsequent synthesis is around 2 to 1. Therefore the WYSG process has excess hydrogen which is ultimately used as a fuel. As a result the process has a smaller carbon footprint than a conventional GTL plant.

Syngas is converted into methanol with 60 % carbon conversion efficiency in the syngas-to-methanol (STM) step. Unconverted syngas is separated from the methanol and used as part of the fuel mix to provide heat for the reforming step. Methanol is converted into gasoline, light hydrocarbons such as propane, and water in the methanol-to-gasoline (MTG) step. These three product phases are separated and put to different uses. The gasoline is the final product of the plant, and is stored in tanks and ultimately transported to the customers. Light hydrocarbons are used as another part of the fuel mix to provide heat for the reforming step. Water is recycled with fresh make-up water used to make steam for reforming.

The product of the WYSG plant is gasoline. Based on the composition description presented in Table 1, and the overall product characteristics displayed in Table 2, the WYSG product closely fits the refinery stream description of naphtha based on boiling range. Naphtha can be used as a feedstock for both gasoline manufacturing and petrochemicals depending on its quality, with light or

paraffinic naphtha usually used in petrochemical plants and heavy naphtha usually used in reformers at refineries to make gasoline. Figure 4 shows locations in a refinery (circled in red) where the WYSG product could be fed. The easiest refinery disposition is the final product blending whereby the WYSG product goes into the main gasoline blending tanks at the refinery. The most logical location to place the product is upstream of any naphtha hydrotreating unit (coker, FCC, pre-isomerization, pre-reformer). With this approach, any shortcomings with the product such as durene content would be readily dealt with within the hydrotreater.

Table 1. Typical product distillation

Component	Vol%
Methane	0.75
Ethane	0.35
Propylene	0.30
Propane	4.20
Butylenes	1.50
Butane	11.20
C5+'s	81.70

TBP of C5+'s, Vol%	
Dist (%)	T (F)
IBP	87.6
10	111.0
30	158.0
50	205.4
70	266.3
90	336.6
95	359.1
98	377.8
EBP	400.1

Table 2. Expected product specifics

C5+ Nonaromatics	51 wt%
Aromatics	49 wt%
Aromatics 6-10	98.7 wt% of total aromatics
A 11+ (includes n	1.3 wt% of total aromatics
Durene	2.5 wt%
Approximate RVP	12 psi
Approximate RON	92
Sulfur	0 ppm
Benzene	0.3 vol%

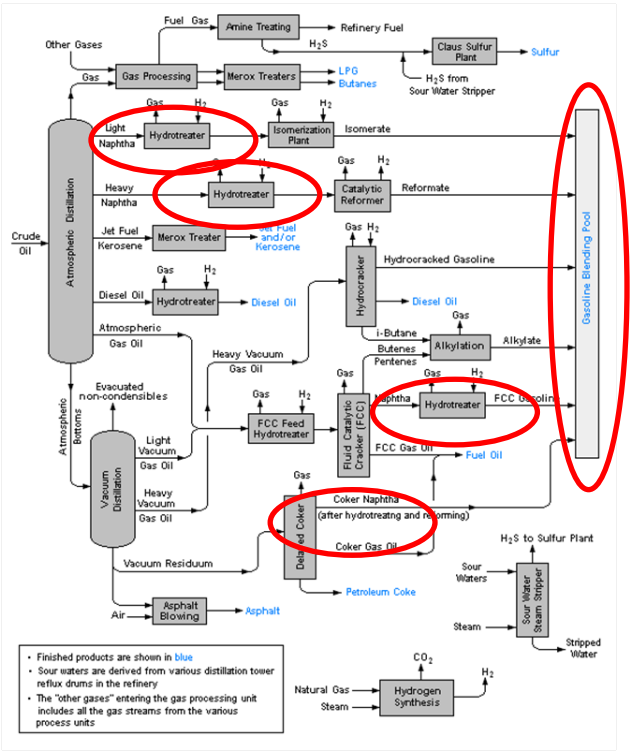

Figure 4 Typical Refiinery configuration (Source: AIChE refinery handbook)

The WYSG product can be delivered to local refineries as an intermediate product stream in Wyoming (Frontier), Colorado (Suncor-Denver), and in Montana. Connacher in Montana – transports diluent to OilSands via rail (600 Bbl cars) to dilute bitumen for pipeline transport to refineries. A secondary disposition could be petrochemical operators such as ethylene producers (Exxon Joliet, Illinois).

The lowest value disposition for the WYSG product is as feed to a refiner's naphtha hydrotreater or directly to its naphtha reformer. Based on current WTI pricing of $89/bbl, WYSG product price would be around $94/bbl or $5/bbl above WTI before discount/premium. As product grade naphtha for sale to OilSands diluent users the price would be $98/bbl (+$9/bbl above WTI). If the product directly is used directly in the gasoline blending pool the price will be $112/bbl (+$23/bbl).

Capital investment required for a WYSG plant with production capacity of 150 bpd is estimated to be in the $20 to $30 million range. Increasing the size of the plant to 500 bpd is expected to increase the fixed capital investment to about $40 or $50 million. We make an assumption that a high CO_2 natural gas could be obtained at a well site for less than pipeline prices. If the cost of carbon dioxide-laden natural gas is $2.00 per thousand cubic feet and the selling price of WYSG product is $106 per barrel, annual revenue would be just under $16 million. The annual production cost would be just over $11 million, and a $40 million plant would be paid off in less than 9 years. After feedstock costs, labor costs are a major component of the production cost. Remote monitoring, controls and operations of several facilities from a central facility improve the process economics dramatically.

The basic siting requirements for the WYSG plant are availability of space, supply of natural gas, water, power and year round access. Natural gas requirements for the reference 150 bpd plant are around 3MMscf/d at a pressure about 20 psi. Water needed for the process is in the 10 – 12 gpm range. Excluding product storage, plant can be located on less than an acre. Other needs include about 2.0 megawatts, 3-phase, 480 volt power, and year-round access road.

Operators of natural gas-producing wells are necessarily careful to avoid disclosing business-confidential information about their production. Accordingly, the research into the logistics of siting a WYSG-like GTL facility is limited. High-level conversations with several industry contacts were helpful in uncovering information about what sites in Wyoming would be good candidates for this type of facility. In spite of the need to keep certain information confidential, interest in GTL technology is quite high.

It will be difficult to find stranded gas wells that produce singly, or from a pod of wells, the approximate 3MMscf/d required by the smallest WYSG plant. The consensus opinion among operators we spoke with was that wells with such flow capacity would already be connected to commercial production. Because of proximity to power and access issues, newly drilled frontier wells with high productive potential may also not be ideal. With these considerations in mind, first WYSG plant should be located at an established production site. Power considerations also favor locating the WYSG plant relatively close to an established production or gas processing facility. An

alternate possibility is using portable natural gas or diesel fueled generators. Natural gas is significantly cheaper than electricity on a gross power basis.

Water is a protected commodity in Wyoming. Accordingly, the WYSG plant is designed with a water treatment capability to reuse, to the maximum extent possible, the approximate 350 barrels of water per day (bwpd) required by the facility. Although the usage is low in absolute terms, a source of water is critical to the operation of the WYSG plant. Sourcing water is highly site specific. Locating near CBM wells provides the highest probability of finding reasonable quality water. Another possibility is locating near a source of relatively clean water such as rivers, lakes or water impoundments where temporary water rights can be secured. Alternatively the plant may be located near a city where water can be trucked in.

The current expectation is that the WYSG plant can be sited on property leased by the natural gas operator. If this is not the case, additional property will have to be acquired from the landowner. The footprint of the 100 – 500 bpd plant is quite small requiring less than an acre.

The quality of access roads to a well site is generally proportional to the degree of development in an area (i.e. number of wells drilled). Roads to frontier wells might be in rough condition and poorly maintained, making year around access difficult. Regardless of general road condition, a high probability exists that because of adverse weather, that the plant site will not be accessible on a year-round basis. Accordingly, the facility must be designed for remote monitoring and control.

Operators that produce natural gas with elevated levels of CO_2 will benefit from supplying the WYSG plants. The compressor company assesses the gas producer additional fees based on the increased power required to compress CO_2 compared to natural gas, if CO_2 levels are greater than 2-to-3%. A potential additional fee might also be assessed for blending out the contaminant to meet interstate pipeline specifications. The WYSG process operates efficiently using natural gas with elevated levels of CO_2, so the commodity can be purchased at a price higher than the prevailing rates. Of course, CO_2 considerations suggest that WYSG process should be near CBM natural gas production.

The Wyoming statutes likely authorize oversight of WYSG-like GTL facilities and processes from the following agencies: Wyoming OSLI for siting on state lands; Wyoming DEQ Divisions, Air Quality, Solid and Hazardous Waste, and Water Quality. Each of these agencies may require permits for the following:

- OSLI: Special Use Lease for siting WYSG facility if on State Lands.
- DEQ – AQD: Minor Source Permit regulating entire WYSG facility; however, WYSG facility may qualify for a permit waiver.
- DEQ – SHWD: Oversight required; however, a regulatory determination may be requested to obtain a written opinion as to whether a permit is needed for WYSG facility.
- DEQ – WQD: General Permit Storm Water Pollution Prevention Plan (SWPPP).
- State Engineer's Office: Permit to appropriate surface or ground water necessary to meet the water requirements of the facility and process.

- County Zoning: Potential zoning requirements or permits; potential requirements will vary by County.

Several potential hurdles exist where either the statutes are silent or vague as far as they would affect WYSG-like GTL facilities or the WYSG process, those include:

- OGCC: Regarding whether or not the WYSG process should be considered production or post-production for natural gas operations, and whether or not the OGCC has authority to regulate the sale of natural gas from the producer directly to the end user.
- PSC: Regarding whether or not the PSC or the Supreme Court might view WRI as 'one end user,' the Court's factor for determining if the natural gas sale qualifies as a sale "to or for the public."
- Siting Issues: Including surface leasing and right to use the surface.
- DEQ-AQD: Whether or not the agency should seek to assume primacy over the PSD program, including CO_2 regulation, in lieu of the EPA regulating and issuing PSD permits within Wyoming.

Potential incentives and recommendations for encouraging natural gas value-added products in Wyoming, such as proposed WYSG facility, include statutory changes and tax incentives which include the following considerations.

The OGCC may need to determine whether or not a value-added products facility is part of the natural gas production or post-production. Such a determination may dictate whether or not the OGCC has jurisdiction to regulate natural gas value-added products. The legislature may choose to make such a determination for the agency, in which case a statutory change might provide the necessary certainty for natural gas value-added product production. More research is needed regarding potential OGCC jurisdiction over natural gas value-added products.

Due to the uncertainty regarding PSC jurisdiction, it is recommended that the state legislature examine this issue and consider an additional exemption in W.S. § 37-1-101(a)(vi)(G) that provides a specific exemption for natural gas value-added products from PSC jurisdiction. This issue may need additional research to fully understand the broader implications.

The legislature may consider including WYSG in 30-5-401 for oil and gas operations only for purposes of gaining access under the statute and for ensuring surface use agreements. However, this raises problematic eminent domain issues given the current eminent domain climate in Wyoming. This issue needs more analysis and consideration of the potential siting hurdles for natural gas value-added products facilities before making any changes to the current law.

The Wyoming State Legislature requested the DEQ-AQD to examine the federal PSD permitting program, which includes CO_2 permitting, and study the potential impacts to Wyoming if the state chose to seek primacy authority to regulate PSD permits under the DEQ-AQD. If the state assumed its primacy over the PSD program CO_2, the state DEQ-AQD then has the ability to work directly with state value-added production facilities and other CO_2 emission producers to coordinate permitting and reporting efforts. The DEQ-AQD may provide a more in-depth analysis of the potential hurdles

and benefits of state primacy in this area. More research is needed regarding PSD and CO_2 permitting and the implications of assuming state primacy for overseeing the PSD and CO_2 program in Wyoming.

In conclusion, Wyoming's statutory and regulatory framework provides some structure for moving natural gas value-added production, such as WYSG-like GTL facility, forward in Wyoming. The identified issues require more research to fully understand the broader implications for addressing those hurdles and/or gaps in the law. The recommendations above are not conclusive and are merely possibilities that the legislature may choose to consider.

Overall, the results of this feasibility study show that it is technologically, logistically, economically and legally feasible to build and operate a properly scaled WYSG-like GTL plant in Wyoming. From a technological standpoint, all of the steps involved in this process are well established and have been commercially available for decades. Although the investigation of logistics for siting a WYSG-like GTL facility were only explored in generalities, feedback from producers was positive. Several entities have shown interest in smaller-scale GTL facilities and a few are seriously exploring sites in Wyoming. After careful economic scrutiny, the arbitrarily chosen size of 150 bpd production maybe a break even proposition and better suited as a demonstration facility. A plant three times larger (around 500 bpd) would have a payoff period of less than 9 years and seems much more attractive as an investment. Such a plant requires about 10 MMscf/d of natural gas and therefore will more than likely be connected to commercial production on a pipeline. Initial research suggests that a plant at this larger size may still fall below the regulatory thresholds as did the smallest plant.